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(54) **METHOD AND APPARATUS FOR ENCODING
IMAGE AND METHOD AND APPARATUS
FOR DECODING IMAGE USING HUMAN
VISUAL CHARACTERISTICS**

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G06K 9/36 (2006.01)

(52) **U.S. Cl.** **382/232**; 382/236; 382/238;
382/239; 382/251

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382/233, 236, 239, 240, 248, 251; 348/606,
348/607; 375/240.16, 240.29, E7.121, E7.256;
704/222, 219; 706/12, 46; 345/420, 426

See application file for complete search history.

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(57) **ABSTRACT**

An image encoding method and apparatus capable of improving image compression efficiency by using human psycho-visual characteristics are provided. In the image encoding method and apparatus, an image signal component of which amplitude is equal to or less than a just noticeable distortion (JND) that is a minimum limit of a visually noticeable image is not encoded according to image characteristics by using the masking effect of the human visual system (HVS), thereby improving an image compression rate without visible deterioration of image quality.

35 Claims, 14 Drawing Sheets

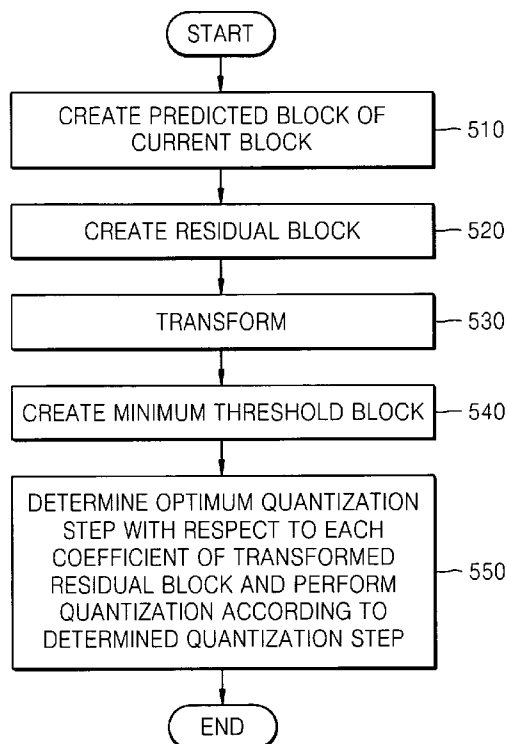


FIG. 1 (RELATED ART)

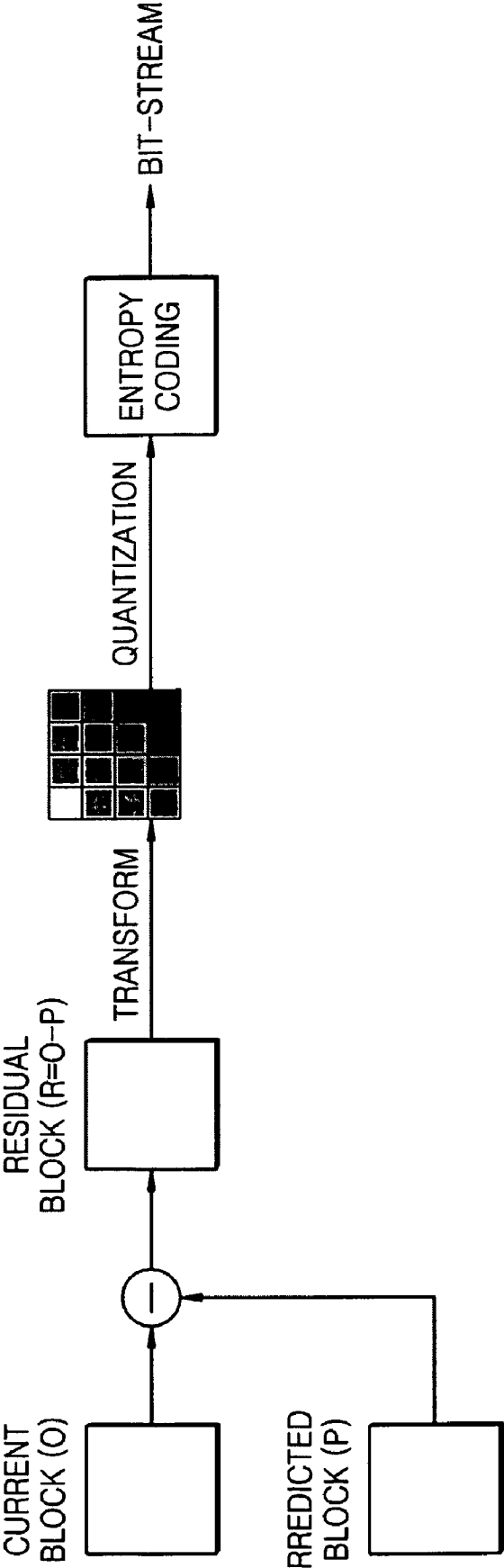


FIG. 2A

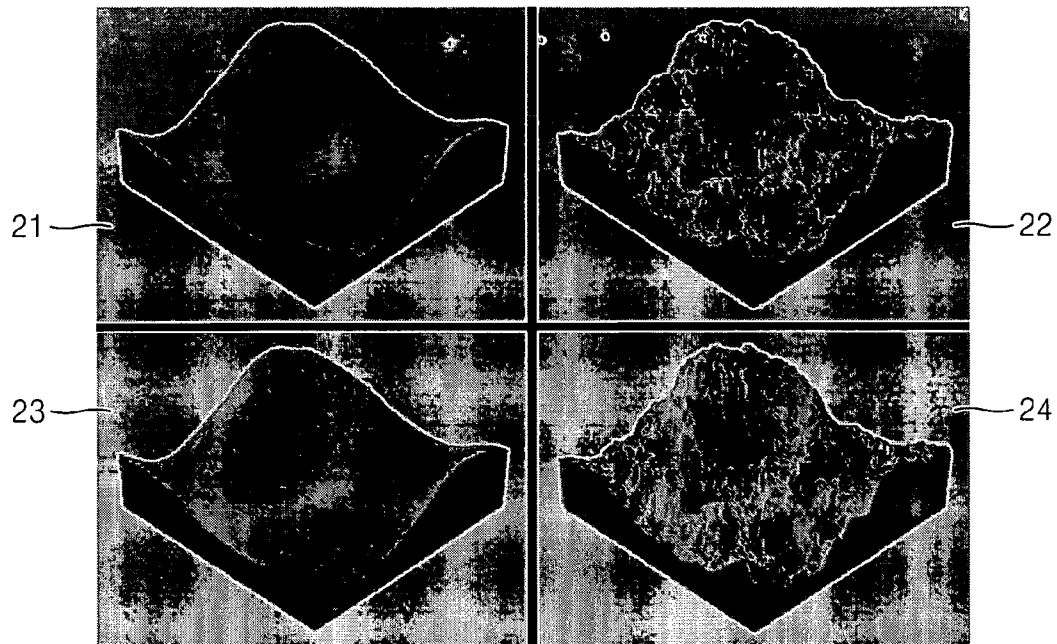


FIG. 2B

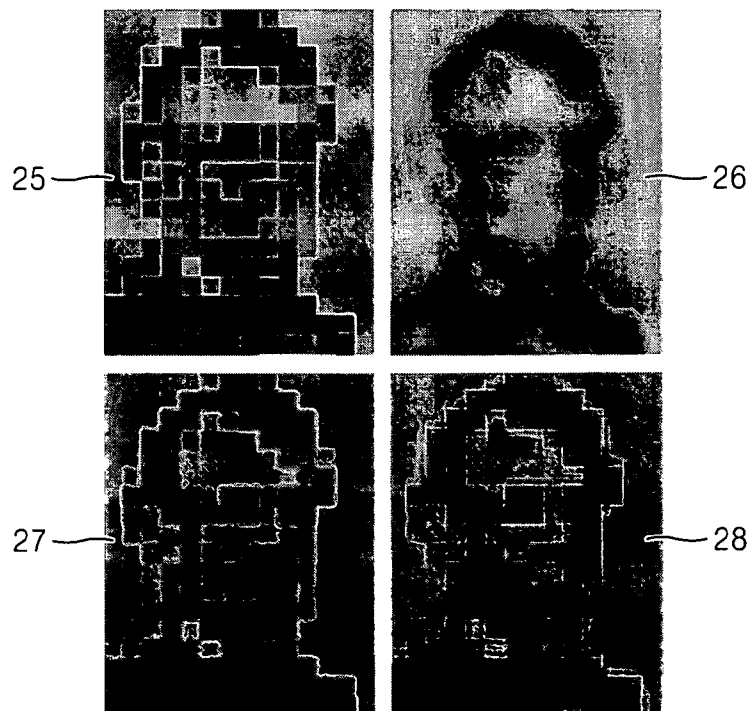


FIG. 3

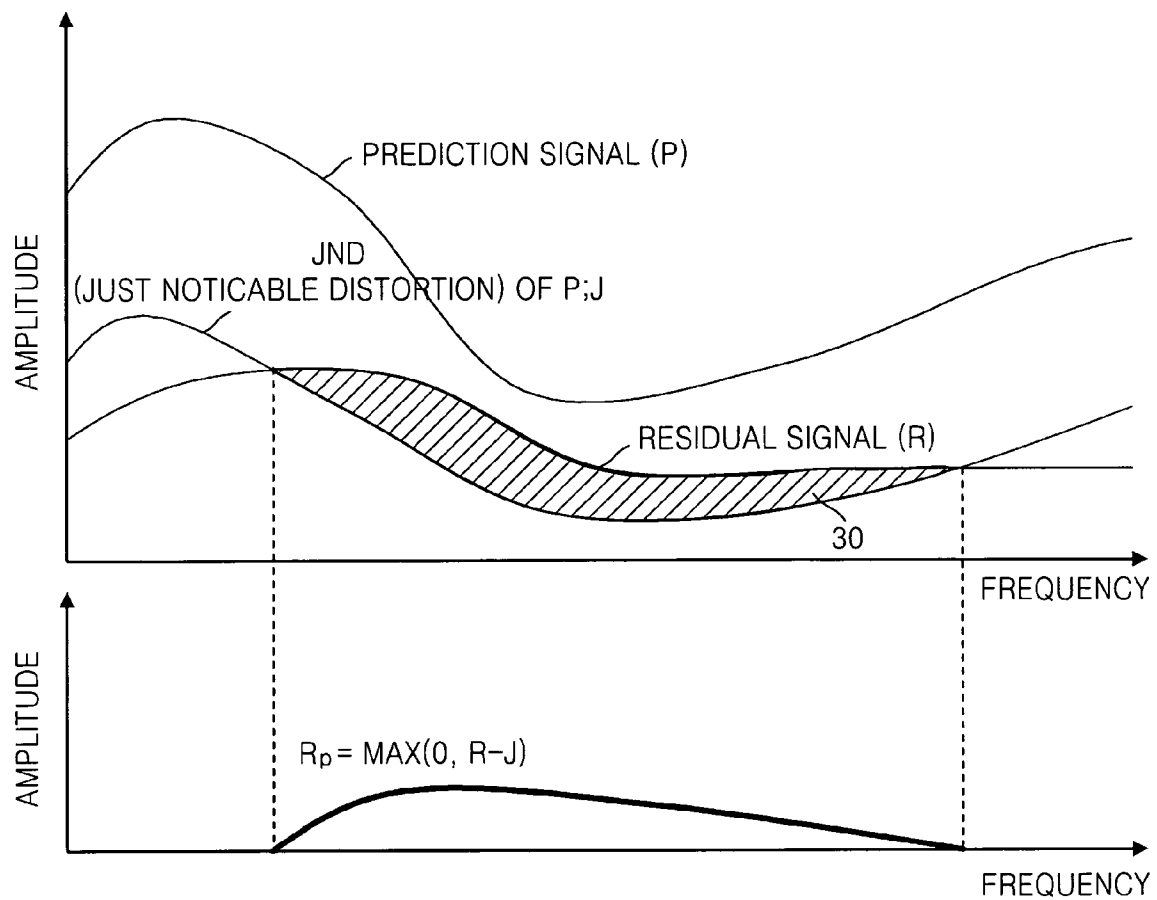


FIG. 4

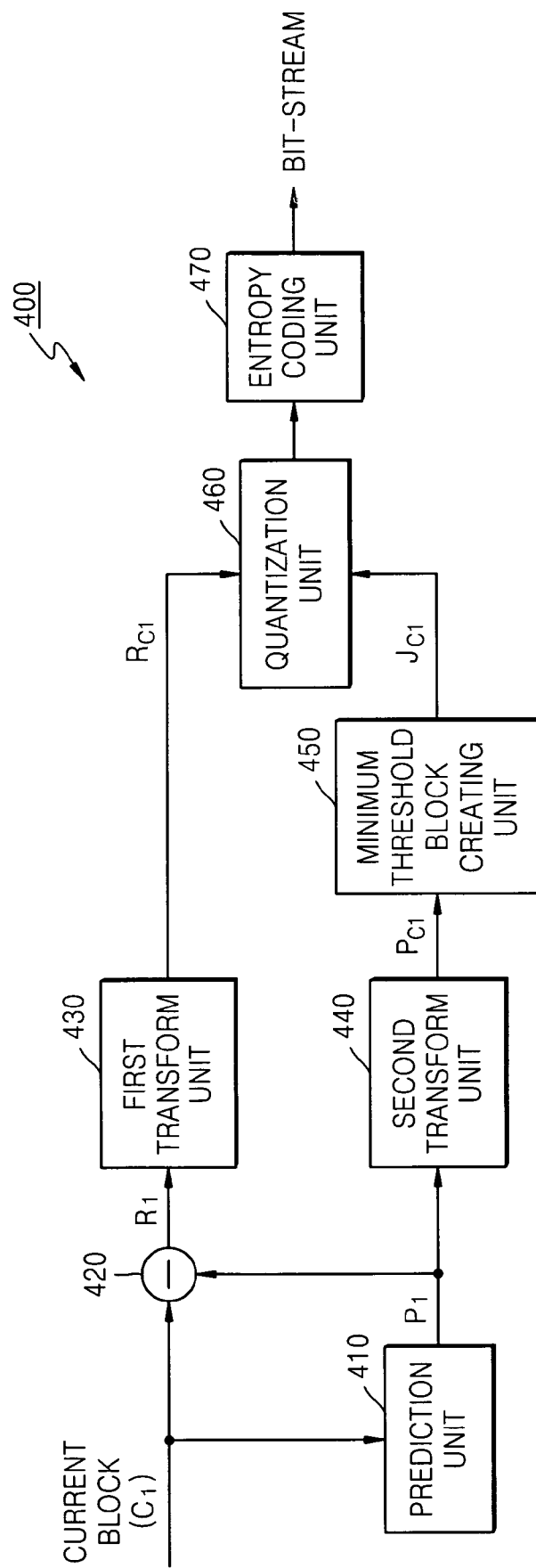


FIG. 5

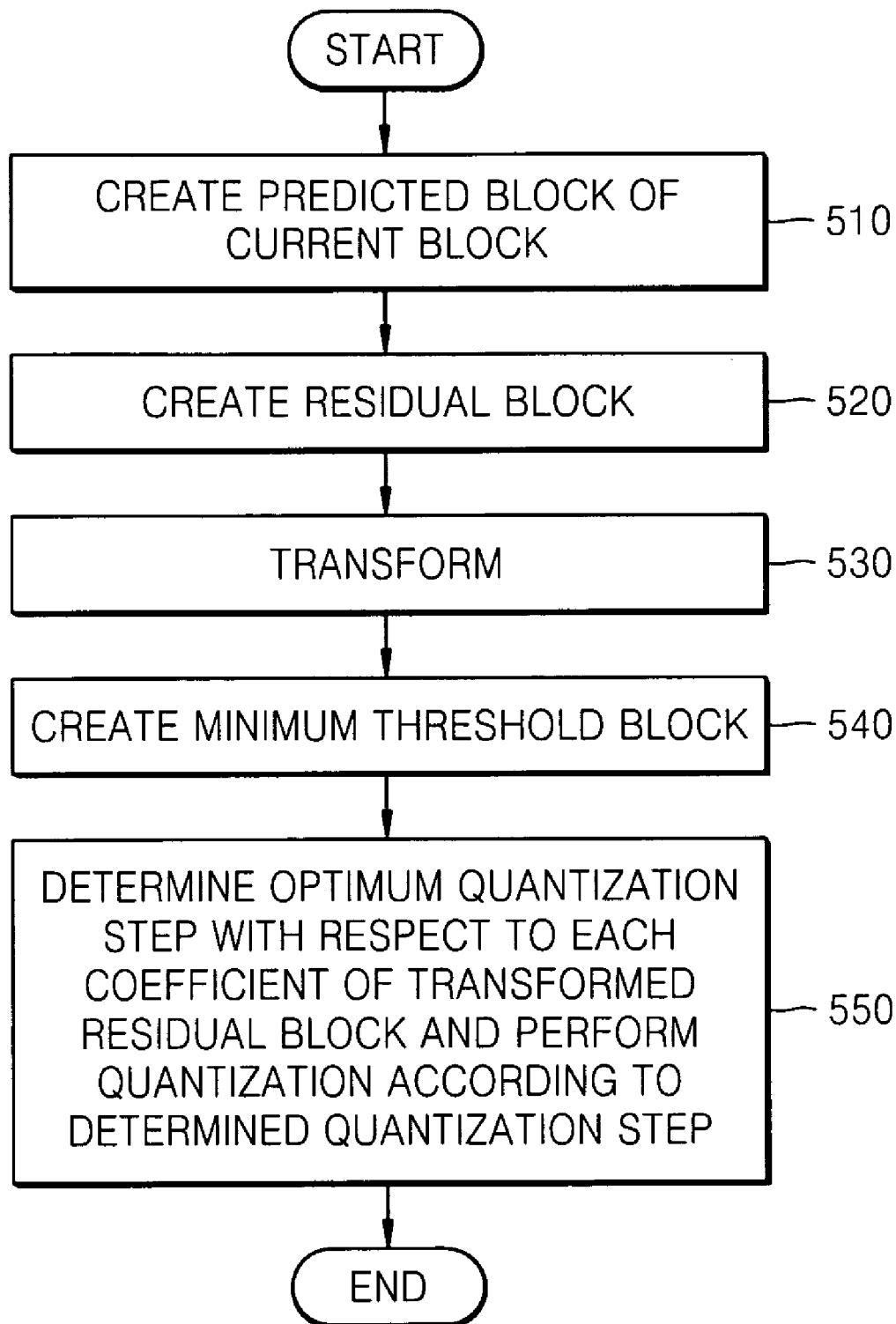


FIG. 6

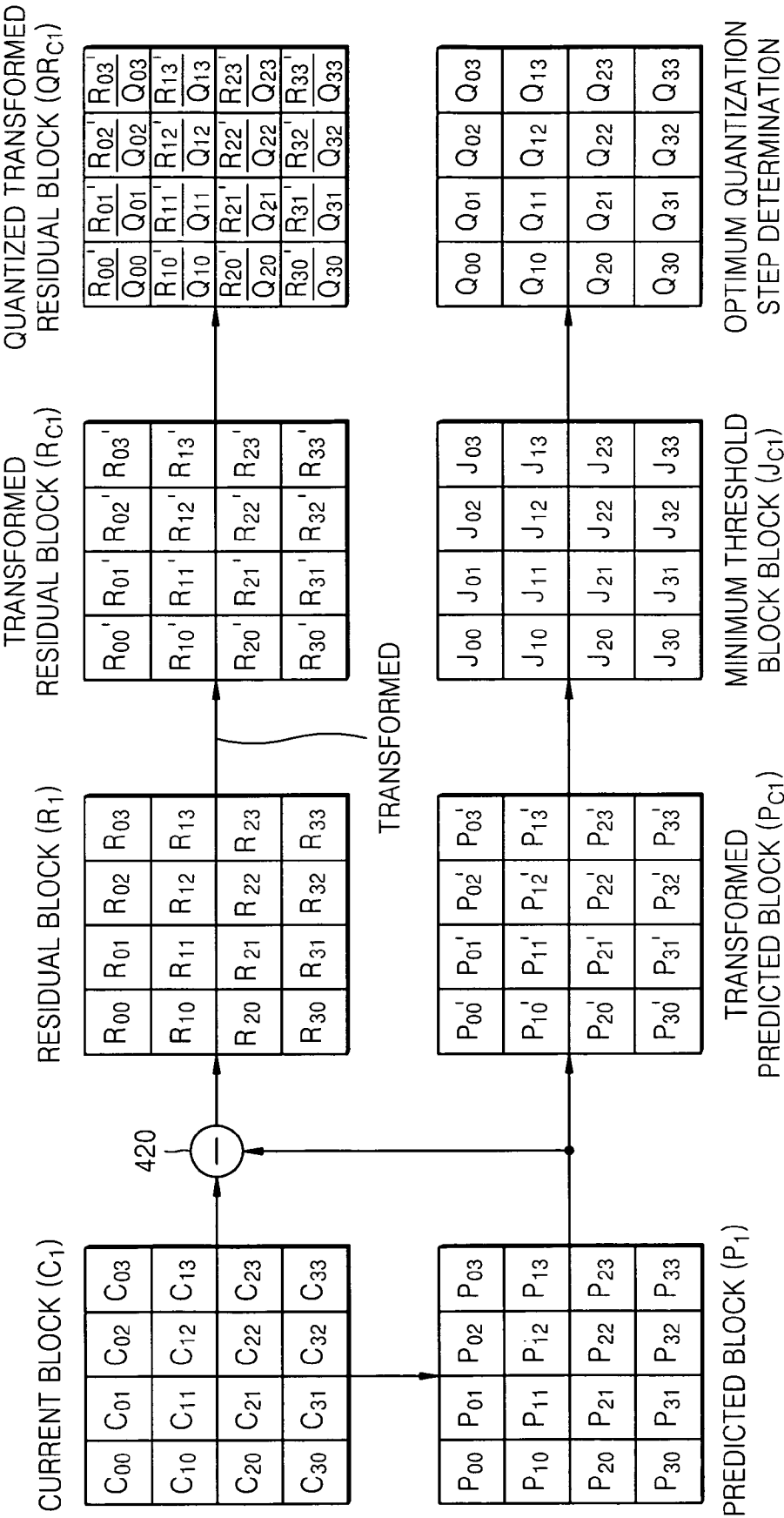


FIG. 7

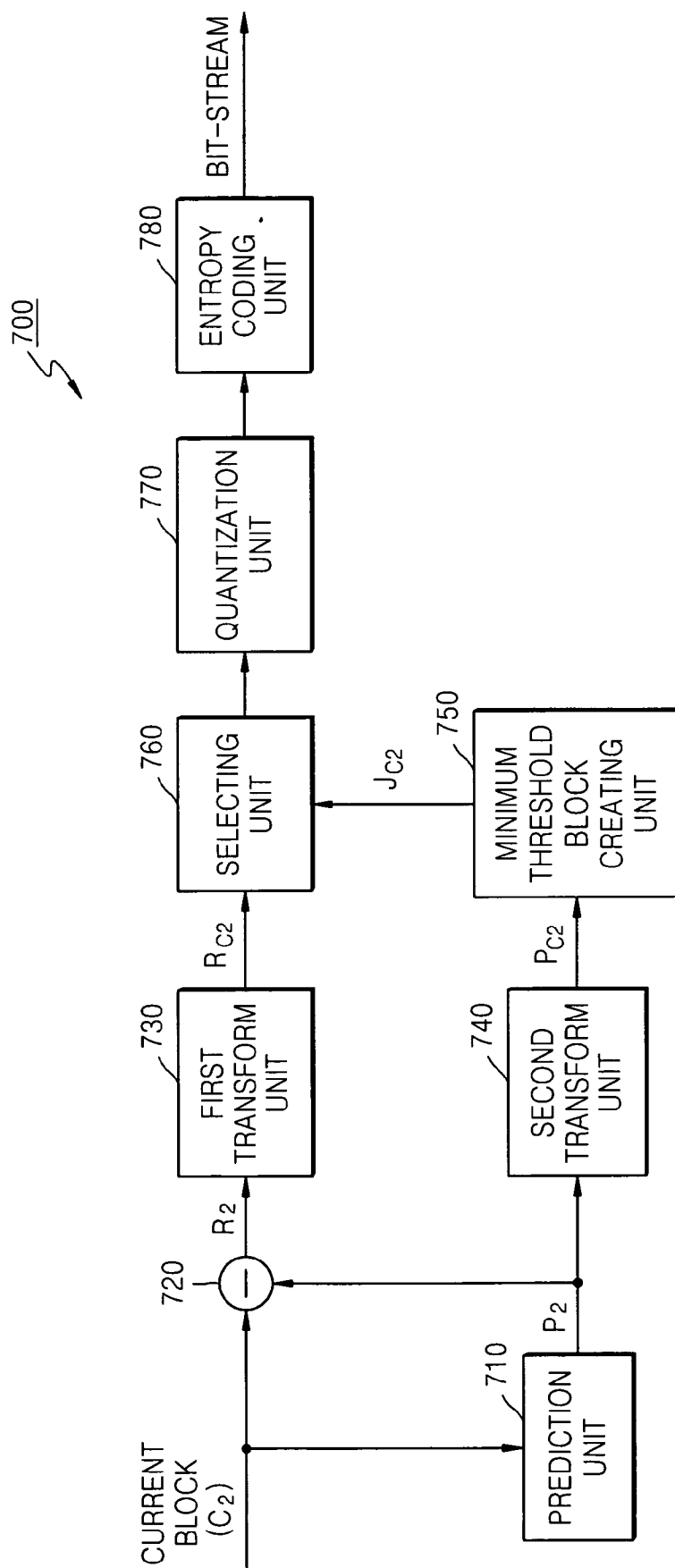


FIG. 8

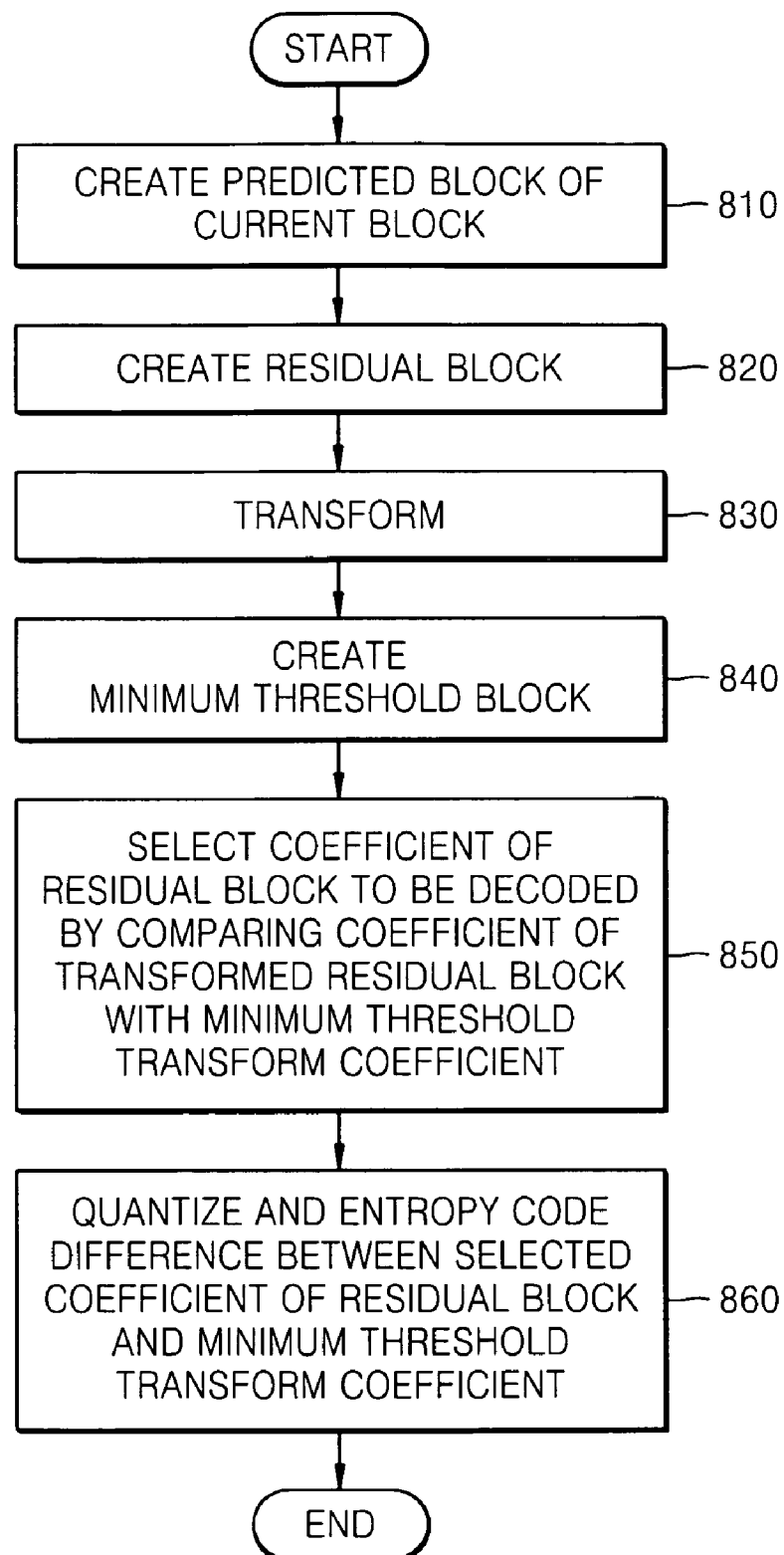


FIG. 9

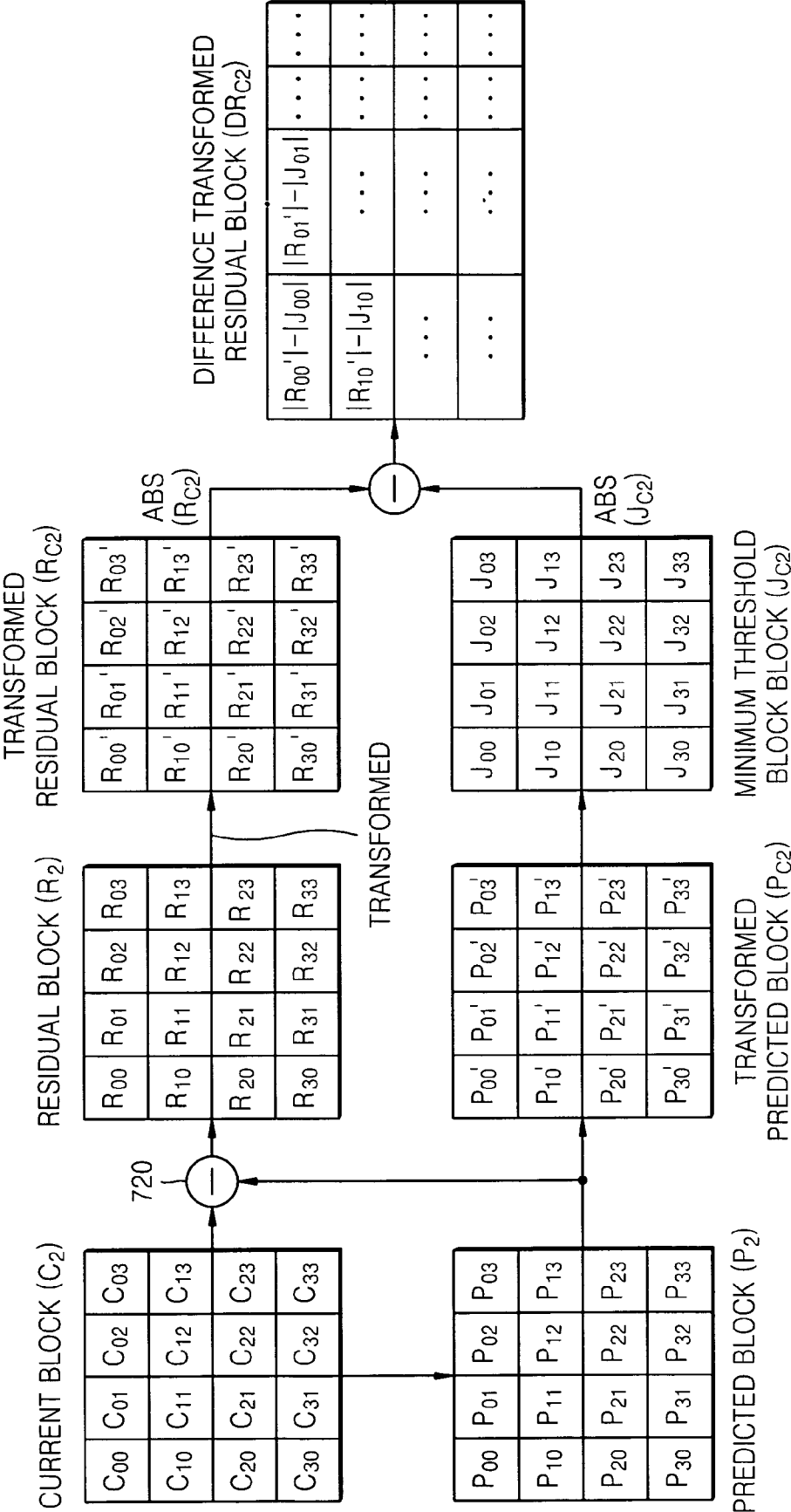


FIG. 10

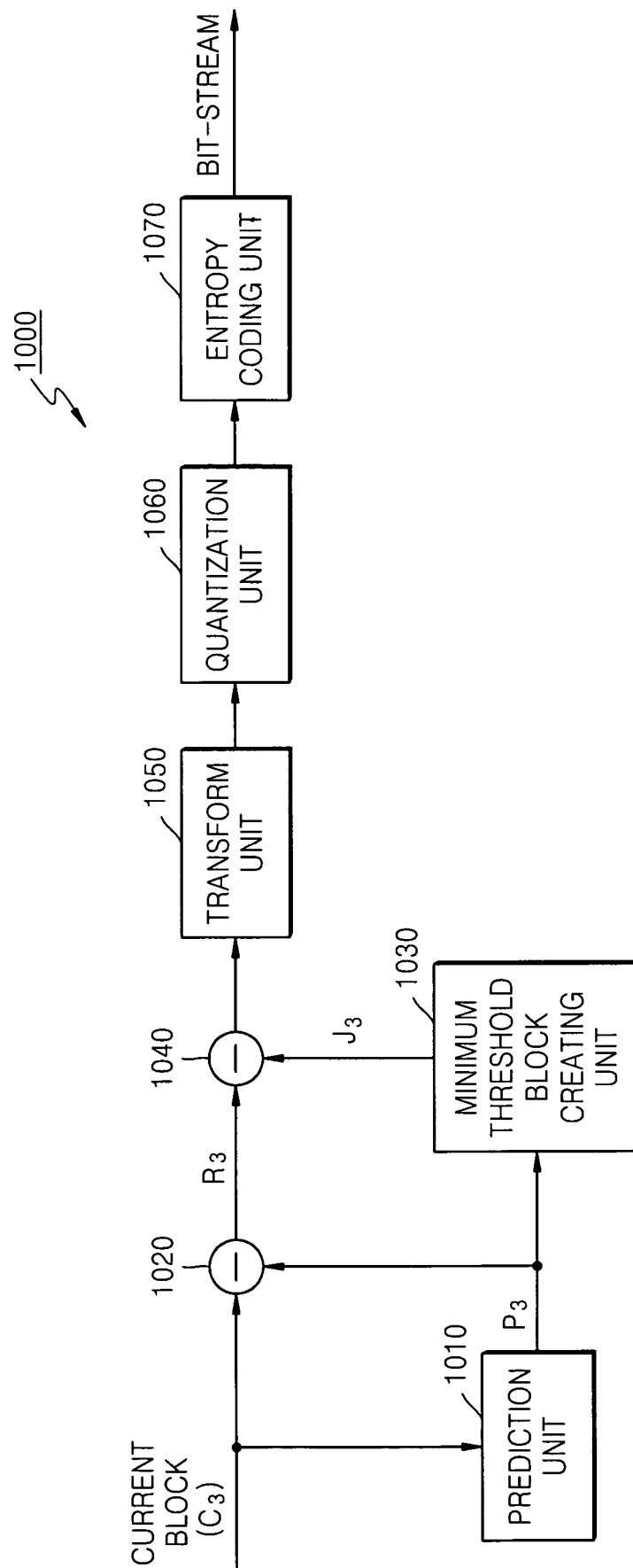


FIG. 11

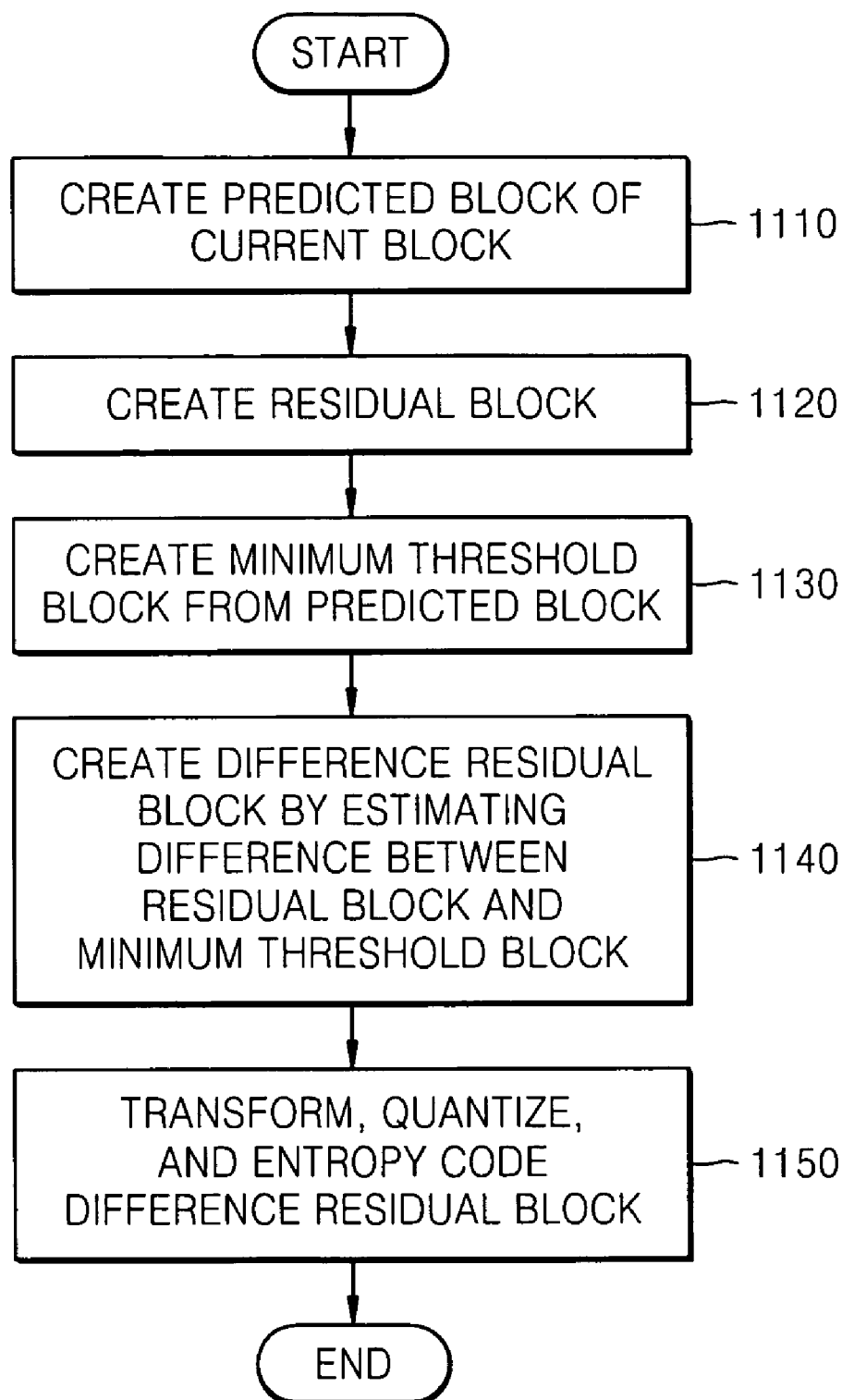


FIG. 12

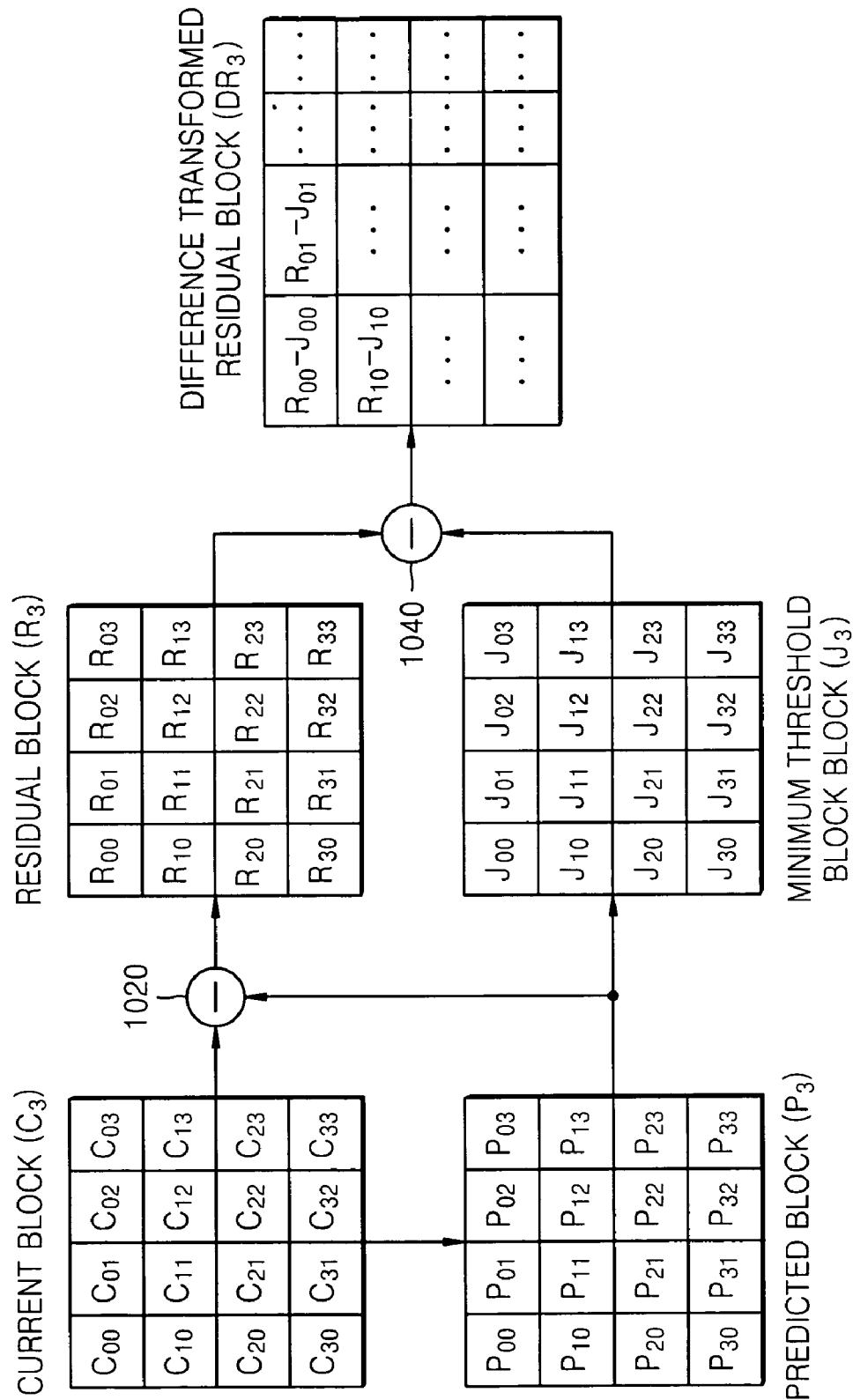


FIG. 13

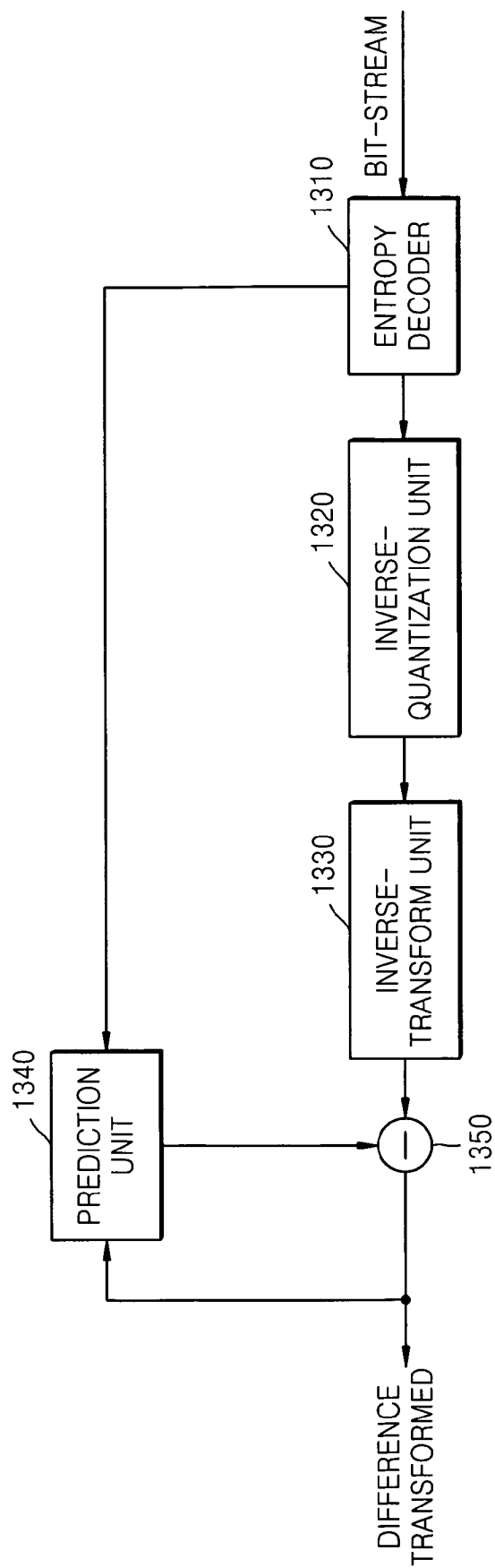
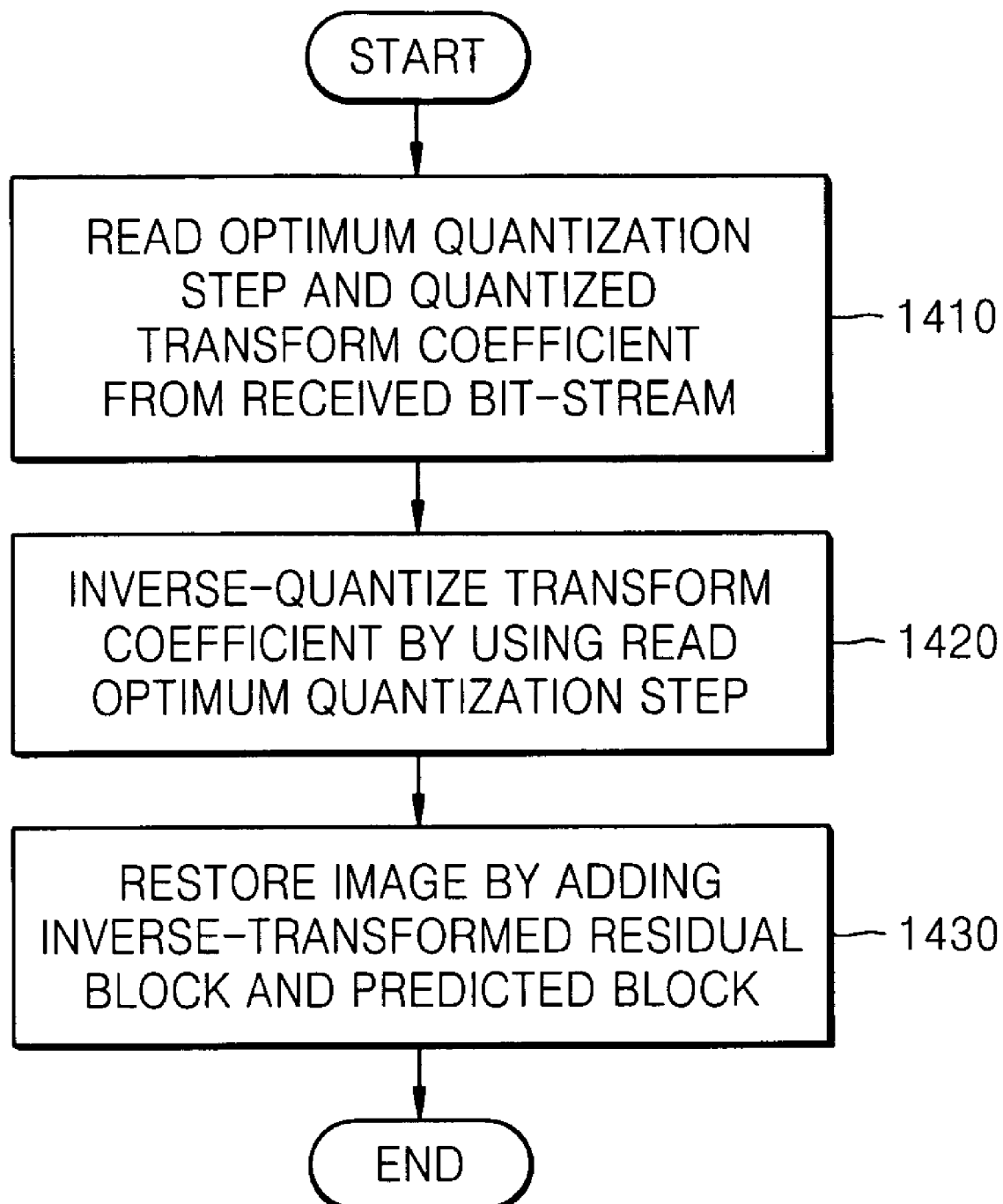


FIG. 14



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METHOD AND APPARATUS FOR ENCODING IMAGE AND METHOD AND APPARATUS FOR DECODING IMAGE USING HUMAN VISUAL CHARACTERISTICS

CROSS-REFERENCE TO RELATED PATENT APPLICATION

This application claims priority from Korean Patent Application No. 10-2005-0109632, filed on Nov. 16, 2005, in the Korean Intellectual Property Office, the disclosure of which is incorporated herein in its entirety by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

Methods and apparatus consistent with the present invention relate to image encoding and decoding, and more particularly, to image encoding and decoding capable of improving image compression efficiency by using human psycho-visual characteristics.

2. Description of the Related Art

FIG. 1 illustrates an example of a related art prediction-based image encoding method.

Referring to FIG. 1, in video compression standards such as MPEG-1, MPEG-2, MPEG-4 Visual, H.261, H.263, and H.264, one frame is divided into a plurality of macro blocks, a prediction process is performed on a macro block basis to obtain a predicted block P corresponding to a current block O, a residual block, which is a difference between the current block O and the predicted block P, is transformed and quantized to reduce the range of a transform coefficient, and entropy coding is then performed.

In a conventional prediction-based image encoding method, a predicted block, i.e., the most similar block to a current block, is obtained by using spatio-temporal correlation of an image in an optimum manner. In the related art prediction-based image encoding method, compression efficiency is enhanced by coding a residual signal that is a difference between the current block and the predicted block. Eventually, in the related art image encoding method, the compression efficiency is determined based on the degree of similarity between the current block and the predicted block.

However, the related art method does not properly use the characteristics of the human visual system when an image is encoded. According to the related art method, a residual block or an entire transformed block is encoded as it is including a portion which cannot be easily visually noticed by a user. In order to overcome a limit in a transfer bandwidth and to provide a high definition image to the user, there is a need for an image encoding method having further improved compression efficiency.

SUMMARY OF THE INVENTION

The present invention provides an image encoding method and apparatus capable of improving image compression efficiency by applying a psycho-visual model using a masking effect of the human visual system to a prediction-based encoding method.

According to an aspect of the present invention, there is provided an image encoding method comprising: creating a predicted block corresponding to a current block to be encoded; creating a residual block by estimating a difference between the current block and the predicted block; creating a transformed residual block and a transformed predicted block by transforming the residual block and the predicted block,

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respectively; obtaining a minimum threshold transform coefficient which allows a corresponding pixel included in the transformed predicted block to be visually noticeable, and creating a minimum threshold block including the minimum threshold transform coefficient; and determining an optimum quantization step which allows a maximum quantization error to be equal to or less than the minimum threshold transform coefficient with respect to a corresponding coefficient of the transformed residual block, and quantizing the corresponding coefficient of the transformed residual block based on the determined optimum quantization step.

According to another aspect of the present invention, there is provided an image encoding method comprising: creating a predicted block corresponding to a current block to be encoded; creating a residual block by estimating a difference between the current block and the predicted block; creating a transformed residual block and a transformed predicted block by transforming the residual block and the predicted block, respectively; obtaining a minimum threshold transform coefficient which allows a corresponding pixel of the transformed predicted block to be visually noticeable, and creating a minimum threshold block including the minimum threshold transform coefficient; and selecting a coefficient of the transformed residual block to be encoded from coefficients of the transformed residual block by comparing the minimum threshold transform coefficient with a corresponding coefficient of the transformed residual block.

According to another aspect of the present invention, there is provided an image encoding method comprising: creating a predicted block corresponding to a current block to be encoded; creating a residual block by estimating a difference between the current block and the predicted block; obtaining a minimum threshold coefficient which allows a corresponding pixel included in the predicted block to be visually noticeable, and creating a minimum threshold block including the minimum threshold coefficient; and creating a difference residual block by estimating a difference between the minimum threshold coefficient and a corresponding coefficient of the residual block.

According to another aspect of the present invention, there is provided an image encoding apparatus comprising: a prediction unit which creates a predicted block corresponding to a current block to be encoded; a subtraction unit which creates a residual block by estimating a difference between the current block and the predicted block; a first transform unit which creates a transformed residual block by transforming the residual block; a second transform unit which creates a transformed predicted block by transforming the predicted block; a minimum threshold block creating unit which obtains a minimum threshold transform coefficient which allows a coefficient included in the transformed predicted block to be visually noticeable, and creates a minimum threshold block comprising the minimum threshold transform coefficient; and a quantization unit which determines an optimum quantization step which allows a maximum quantization error to be equal to or less than the minimum threshold transform coefficient with respect to a corresponding coefficient of the transformed residual block, and quantizes the corresponding coefficient of the transformed residual block based on the determined optimum quantization step.

According to another aspect of the present invention, there is provided an image encoding apparatus comprising: a prediction unit which creates a predicted block corresponding to a current block to be encoded; a subtraction unit which creates a residual block by estimating a difference between the current block and the predicted block; a first transform unit which creates a transformed residual block by transforming

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the residual block; a second transform unit which creates a transformed predicted block by transforming the predicted block; a minimum threshold block creating unit which obtains a minimum threshold transform coefficient which allows a coefficient included in the transformed predicted block to be visually noticeable, and creates a minimum threshold block comprising the minimum threshold transform coefficient; and a selecting unit which selects a coefficient of a transformed residual block to be encoded from coefficients of the transformed residual block by comparing the minimum threshold transform coefficient with a corresponding coefficient of the transformed residual block.

According to another aspect of the present invention, there is provided an image encoding apparatus comprising: a prediction unit which creates a predicted block corresponding to a current block to be encoded; a first subtraction unit which creates a residual block by estimating a difference between the current block and the predicted block; a minimum threshold block creating unit which obtains a minimum threshold coefficient which allows a corresponding pixel included in the predicted block to be visually noticeable, and creates a minimum threshold block comprising the minimum threshold coefficient; and a second subtraction unit which creates a difference residual block by estimating a difference between the minimum threshold coefficient and a corresponding coefficient of the residual block.

According to another aspect of the present invention, there is provided an image decoding method comprising: reading information on an optimum quantization step, which is determined such that a maximum quantization error is equal to or less than a minimum threshold transform coefficient with respect to each coefficient of a transformed residual block, and information on a coefficient of the transformed residual block, the coefficient being quantized according to the optimum quantization step, from a received bit-stream; inverse-quantizing the quantized coefficient of the transformed residual block; and restoring an image by adding a predicted block for a current block to be decoded and the inverse-transformed transformed residual block.

According to another aspect of the present invention, there is provided an image decoding apparatus comprising: an entropy decoder which reads information on an optimum quantization step, which is determined such that a maximum quantization error is equal to or less than a minimum threshold transform coefficient with respect to each coefficient of a transformed residual block, and information on a coefficient of the transformed residual block, the coefficient being quantized according to the optimum quantization step, from a received bit-stream; an inverse-quantization unit which inverse-quantizes the coefficients of the transformed residual block, which are quantized according to the read optimum quantization step; an inverse-transform unit which outputs a residual block by inverse-transforming the quantized coefficient of the transformed residual block; a prediction unit which creates a predicted block for a current block to be decoded; and an add unit which restores an image by adding the inverse-transformed residual block and the predicted block.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other aspects of the present invention will become more apparent by describing in detail exemplary embodiments thereof with reference to the attached drawings, in which:

FIG. 1 illustrates an example of a related art prediction-based image encoding method;

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FIGS. 2A and 2B are views for explaining a masking effect of a human visual system (HVS) used according to an exemplary embodiment of the present invention;

FIG. 3 is a view for explaining a concept of an image encoding method using human visual characteristics according to an exemplary embodiment of the present invention;

FIG. 4 is a block diagram of an image encoding apparatus according to an exemplary embodiment of the present invention;

FIG. 5 is a flowchart of an image encoding method according to an exemplary embodiment of the present invention;

FIG. 6 illustrates blocks respectively created in operations of an image encoding method according to an exemplary embodiment of the present invention;

FIG. 7 is a block diagram of an image encoding apparatus according to another exemplary embodiment of the present invention;

FIG. 8 is a flowchart of an image encoding method according to another exemplary embodiment of the present invention;

FIG. 9 illustrates blocks respectively created in operations of an image encoding method according to another exemplary embodiment of the present invention;

FIG. 10 is a block diagram of an image encoding apparatus according to still another exemplary embodiment of the present invention;

FIG. 11 is a flowchart of an image encoding method according to still another exemplary embodiment of the present invention;

FIG. 12 illustrates blocks respectively created in operations of an image encoding method according to still another exemplary embodiment of the present invention;

FIG. 13 is a block diagram of an image decoding apparatus according to an exemplary embodiment of the present invention; and

FIG. 14 is a flowchart of an image decoding method according to an exemplary embodiment of the present invention.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

Hereinafter, the present invention will be described in detail by explaining exemplary embodiments of the invention with reference to the attached drawings.

The characteristics of the human visual system (HVS) will be first described. Similarly to the human auditory system, the HVS has a masking effect. The masking effect in this case means that, when an image signal has a component greater than a predetermined amplitude at a particular frequency, a signal of which amplitude is less than the predetermined amplitude and which exists at a frequency band around the particular frequency cannot be noticed by a user, or an image signal of which amplitude is less than the predetermined amplitude cannot be noticed according to the image characteristics.

FIGS. 2A and 2B are views for explaining the masking effect of the HVS used in an exemplary embodiment of the present invention. Images 21 and 22 shown in the upper portion of FIG. 2A are quantized with eight-bit precision, and images 23 and 24 shown at the lower portion of FIG. 2A are quantized with four-bit precision.

When the images 22 and 24 of FIG. 2A having rough surfaces are compared with each other, a difference between an image quantized with eight-bit precision and an image quantized with four-bit precision is not easily visually noticeable. Meanwhile, when the images 21 and 23 having smooth

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surfaces are compared with each other, it can be seen that a banding effect is more apparent in the image quantized with four-bit precision than the image quantized with eight-bit precision. An encoded image may have an improved compression rate when a portion which is not visually noticeable by a user is not encoded, by controlling a quantization coefficient according to image characteristics.

In a first image **25** of FIG. **2B**, an image of a person (i.e., Abraham Lincoln) with a continuous tone is sampled after low-pass filtered at 10 cycles/picture. In a second image **26** of FIG. **2B**, the first image **25** is again low-pass filtered. In a third image **27**, a high frequency band component equal to or greater than 40 cycles is removed from the first image **25**. In a fourth image **28**, a frequency band component in the range of 12-40 cycles is removed from the first image **25**.

When the first image **25** and the second image **26** of FIG. **2B** are compared with each other, visual recognition increases when discontinuous edge portions of blocks having a high frequency band component are removed through a low pass filter. However, not only the high frequency band component affects human visual recognition. Referring to the third image **27** and the fourth image **28** of FIG. **2B**, visual recognition increases more in the fourth image **28** in which only a particular frequency band component in the range of 12-40 cycles is removed than the third image **27** in which a high frequency band component equal to or greater than 40 cycles is removed. The masking effect occurs when the limited frequency band components interact, and an image can be compressed with little difference in terms of visual recognition by removing only a particular frequency band component according to image characteristics.

According to an exemplary embodiment of the present invention, an image signal component of which amplitude is equal to or less than a just noticeable distortion (JND), which is a minimum limit of a visually noticeable image, is not encoded according to image characteristics by using the masking effect of the human visual system, thereby improving an image compression rate without subjective deterioration of image quality.

FIG. **3** is a view for explaining a concept of an image encoding method using human visual characteristics according to an exemplary embodiment of the present invention.

Assume that a prediction signal **P** is a signal predicted from an original image signal through intra-prediction or inter-prediction, a JND **J** is a minimum limit of a visually noticeable signal of the prediction signal **P**, and a residual signal **R** **32** is a difference between the original image signal **O** and the prediction signal **P**. Referring to FIG. **3**, in the image encoding method of an exemplary embodiment of the present invention, the JND **J**, which is a minimum limit of a visually noticeable image, is estimated from the prediction signal **P**, and the residual signal **R** that is smaller than the JND **J** is not encoded, resulting in effective compression. In other words, only a difference MAX (**O**, **R**-**J**) between the JND **J** and a residual signal portion **30** greater than the JND **J** is encoded, thereby improving image compression efficiency.

To this end, in an image encoding method and apparatus of the exemplary embodiment of present invention, data to be encoded is determined by taking the characteristics of the JND into account in a quantization operation, a transform operation, and a residual signal processing operation. Now, the image encoding method and apparatus of the exemplary embodiment of the present invention will be described by explaining exemplary embodiments of the invention with respect to each of the operations.

FIG. **4** is a block diagram of an image encoding apparatus according to an exemplary embodiment of the present inven-

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tion. FIG. **5** is a flowchart of an image encoding method according to an exemplary embodiment of the present invention. FIG. **6** illustrates blocks respectively created in operations of an image encoding method according to an exemplary embodiment of the present invention. The image encoding method and apparatus of the present according to an exemplary embodiment of the present invention will now be described with reference to FIGS. **4** to **6**.

In the method and apparatus according to an exemplary embodiment of the present invention, a quantization step is controlled to allow a quantization error generated in the quantization operation to be equal to or less than a specific visually noticeable threshold coefficient, that is, the JND.

Referring to FIG. **4**, an image encoding apparatus **400** includes a prediction unit **410**, a subtraction unit **420**, a first transform unit **430**, a second transform unit **440**, a minimum threshold block creating unit **450**, a quantization unit **460**, and an entropy coding unit **470**.

Referring to FIG. **5**, in operation **510**, the prediction unit **410** performs intra-prediction or inter-prediction with respect to a current block C_1 that is input on the basis of a specific sized block to be encoded, thereby creating a predicted block P_1 corresponding to the current block C_1 .

In operation **520**, the subtraction unit **420** subtracts the predicted block P_1 from the current block C_1 , thereby creating a residual block R_1 . Referring to FIG. **6**, a pixel R_{xy} located at the position (x, y) of the residual block R_1 has a value obtained by subtracting a pixel P_{xy} of a corresponding predicted block from a pixel C_{xy} included in the current block, which is $R_{xy} = C_{xy} - P_{xy}$.

In operation **530**, the first transform unit **430** and the second transform unit **440** perform a frequency transform such as a discrete cosine transform (DCT) or a wavelet transform, thereby creating a transformed residual block R_{c1} and a transformed predicted block P_{c1} from the residual block R_1 and the predicted block P_1 , respectively.

In operation **540**, the minimum threshold block creating unit **450** obtains minimum threshold transform coefficients which allow each coefficient included in the transformed predicted block P_{c1} to be visually noticeable, and creates a minimum threshold block J_{c1} including the minimum threshold transform coefficients.

In operation **550**, the quantization unit **460** determines an optimum quantization step used to quantize each residual transform coefficient R' of the transformed residual block R_{c1} . The optimum quantization step can be estimated using Formula 1.

[Formula 1]

$$Q_{step}^i = \arg \max_{Q_{step}^i} \{ |(R_i - J_i) - (R_i - J_i)^{Q_{step}^i}| \leq J_i \}$$

In Formula 1, R_i is an i-th coefficient of a transformed residual block, J_i is an i-th minimum threshold transform coefficient of a minimum threshold block, and Q_{step}^i is an optimum quantization step used to quantize the i-th coefficient of the transformed residual block R_{c1} . In addition, $(R_i - J_i)^{Q_{step}^i}$ represents a quantized value of a difference between the transformed residual block R_{c1} and the minimum threshold block J_{c1} according to the optimum quantization step Q_{step}^i .

Referring to Formula 1, the quantization unit **460** may determine the optimum quantization step from a maximum value among quantization step values which allow an absolute value of a quantization error $(R_i - J_i) - (R_i - J_i)^{Q_{step}^i}$ to be equal to or less than a minimum threshold transform coefficient J_i created from the predicted block P_1 . However, when the quantization step is determined using Formula 1, the

coefficients R_i of the transformed residual block cannot be directly used in a decoding end. Therefore, the optimum quantization step may be determined using Formula 2.

[Formula 2]

$$Q_{step}^i = \arg \max_{Q_{step}^i} \{ \text{MaxE}(Q_{step}^i) \leq J_i \}$$

In Formula 2, $\text{MaxE}(Q_{step}^i)$ denotes a maximum quantization error value according to the optimum quantization step Q_{step}^i . For example, if a value of the optimal quantization step Q_{step}^i is a , a maximum quantization error value generated by rounding-off or rounding-down becomes $a/2$. The quantization unit **460** determines the optimum quantization step from a maximum value among quantization step values which allow the maximum quantization error $\text{MaxE}(Q_{step}^i)$ to be equal to or less than a minimum threshold transform coefficient J_i , then quantizes the transformed residual block R_{c1} according to the determined optimum quantization step, and then creates a quantized transformed residual block QR_{c1} . When information on the optimum quantization step Q_{step}^i is transferred while being included in an encoded bit-stream, an inverse-quantization can be carried out in the decoding end with respect to coefficients of the quantized transformed residual block by using information on the transferred optimum quantization step.

Meanwhile, when a significantly high compression rate is required due to a limit in a transfer bandwidth, that is, when an assignable bit is limited, and when encoding is performed using a quantization step obtained by Formula 2, a desired bit rate may not be achieved in some cases. In this case, for adaptable use, the optimum quantization step determined by the Formula 2 may be used only when the optimum quantization step is greater than a predetermined quantization step for the coefficients of the transformed residual block. In addition, an average value of the optimum quantization step may change while a relative rate of a quantization step determined by Formula 2 is maintained with respect to coefficients of each transformed residual block, for an adaptive bit assignment according to changes in a bandwidth.

In this manner, image compression efficiency can be improved by controlling a quantization step such that a quantization noise is equal to or less than the JND that is a minimum level noticeable by a human visual system.

FIG. 7 is a block diagram of an image encoding apparatus according to another exemplary embodiment of the present invention. FIG. 8 is a flowchart of an image encoding method according to another exemplary embodiment of the present invention. FIG. 9 illustrates blocks respectively created in operations of an image encoding method according to another exemplary embodiment of the present invention. The image encoding method and apparatus of another exemplary embodiment of the present invention will now be described with reference to FIGS. 7 to 9.

In the image encoding method according to another exemplary embodiment of the present invention, minimum threshold transform coefficients which allow each transform coefficient to be visually noticeable are obtained in the transform operation prior to the quantization operation, and only a transformed residual block portion of which coefficient is greater than the minimum threshold transform coefficients is encoded.

Referring to FIG. 7, an image encoding apparatus **700** includes a prediction unit **710**, a subtraction unit **720**, a first transform unit **730**, a second transform unit **740**, a minimum threshold block creating unit **750**, a selecting unit **760**, a quantization unit **770**, and an entropy coding unit **780**.

In operation **810**, the prediction unit **710** performs intra-prediction or inter-prediction with respect to a current block

C_2 that is input on the basis of a specific sized block to be encoded, thereby creating a predicted block P_2 corresponding to the current block C_2 .

In operation **820**, the subtraction unit **720** subtracts the predicted block P_2 from the current block C_2 , thereby creating a residual block R_2 .

In operation **830**, the first transform unit **730** and the second transform unit **740** respectively transform the residual block R_2 and the predicted block P_2 , thereby creating a transformed residual block R_{c2} and a transformed predicted block P_{c2} .

In operation **840**, the minimum threshold block creating unit **750** obtains minimum threshold transform coefficients J which allow each coefficient included in the transformed predicted block P_{c2} to be visually noticeable, and creates a minimum threshold block J_{c2} including the minimum threshold transform coefficients J .

In operation **850**, the selecting unit **760** compares each transformed residual coefficient R' of the transformed predicted block P_{c2} with the minimum threshold transform coefficients J , and determines a coefficient to be encoded among coefficients of the transformed residual block R_{c2} .

Specifically, referring to FIG. 9, the selecting unit **760** calculates a difference between an absolute value $\text{ABS}(R_{c2})$ of a transformed residual coefficient of the transformed residual block R_{c2} and an absolute value $\text{ABS}(J_{c2})$ of a coefficient of the minimum threshold block J_{c2} , and encodes only a portion where the difference is greater than 0. Since a transform coefficient may be a negative value in the case of DCT or the like, an absolute value is used when the transformed residual coefficient and the minimum threshold transform coefficient are compared with each other. If it is assumed that a transformed residual coefficient located at the position (x, y) of the transformed residual block R_{c2} is R_{xy}' , and a coefficient of a corresponding minimum threshold block is J_{xy} , then the selecting unit **760** encodes a transformed residual coefficient when $|R_{xy}'| - |J_{xy}| > 0$, and defines a corresponding transformed residual coefficient to 0 when $|R_{xy}'| - |J_{xy}| < 0$. That is, the selecting unit **760** selects only the transformed residual coefficients R_{xy}' greater than the minimum threshold block J_{xy} , and encodes a difference with respect to the minimum threshold transform coefficients. Also, when the difference transformed residual coefficient is a negative value, that is, the minimum threshold transform coefficients are greater than the difference transformed residual coefficient, the difference transformed residual coefficient is set to 0 to reduce the quantity of information to be encoded.

In operation **860**, the difference transformed residual coefficient, which is a difference between a coefficient of a transformed residual block selected by the selecting unit **780** and the minimum threshold transform coefficient, is again quantized and encoded through the quantization unit **770** and the entropy coding unit **780**, and is output in the form of a bit-stream.

FIG. 10 is a block diagram of an image encoding apparatus according to still another exemplary embodiment of the present invention. FIG. 11 is a flowchart of an image encoding method according to still another exemplary embodiment of the present invention. FIG. 12 illustrates blocks respectively created in operations of an image encoding method according to still another exemplary embodiment of the present invention. The image encoding method and apparatus of the present invention will now be described with reference to FIGS. 10 to 12.

In the image encoding method according to still another exemplary embodiment of the present invention, the JND,

which allows minimum threshold values of each pixel included in a predicted block to be visually noticeable, is obtained prior to the transform operation, and then a difference between a residual value and the minimum threshold value is encoded.

Referring to FIG. 10, an image encoding apparatus 1000 includes a prediction unit 1010, a first subtraction unit 1020, a minimum threshold block creating unit 1030, a second subtraction unit 1040, a transform unit 1050, a quantization unit 1060, and an entropy coding unit 1070.

In operation 1110, the prediction unit 1010 performs intra-prediction or inter-prediction with respect to a current block C_3 that is input on the basis of a specific sized block to be encoded, thereby creating a predicted block P_3 corresponding to the current block C_3 .

In operation 1120, the first subtraction unit 1020 subtracts the predicted block P_3 from the current block C_3 , thereby creating a residual block R_3 .

In operation 1130, the minimum threshold block creating unit 1030 obtains minimum threshold transform coefficients which allow each pixel included in the predicted block P_3 to be visually noticeable, and creates a minimum threshold block J_3 including the minimum threshold transform coefficients.

In operation 1140, the second subtraction unit 1040 estimates a difference between the residual block R_3 and the minimum threshold block J_3 , thereby creating a difference residual block DR_3 . If the difference between the residual block R_3 and the minimum threshold block J_3 is a negative value, a pixel value of the difference residual block DR_3 is set to "0". That is, each pixel of the difference residual block DR_3 has a value of $\max(0, R-J)$.

In operation 1150, the difference between the residual block R_3 and the minimum threshold block J_3 used to constitute the difference residual block is encoded and then the transform operation, the quantization operation, and the entropy coding operation are performed.

FIG. 13 is a block diagram of an image decoding apparatus according to an exemplary embodiment of the present invention. FIG. 14 is a flowchart of an image decoding method according to an exemplary embodiment of the present invention.

Referring to FIG. 13, an image decoding apparatus includes an entropy decoder 1310, an inverse-quantization unit 1320, an inverse-transform unit 1330, a prediction unit 1340, and an add unit 1350.

In operation 1410, the entropy decoder 1310 entropy-decodes a received bit-stream, and reads encoding information such as an optimum quantization step and a quantized transform coefficient which are included in the bit-stream.

In operation 1420, the inverse-quantization unit 1320 inverse-quantizes the read transform coefficient by using the read optimum quantization step, thereby outputting a transform coefficient.

In operation 1430, the prediction unit 1340 performs inter-prediction or intra-prediction with respect to a current block to be decoded according to information on an encoding mode included in the received bit-stream, thereby creating a predicted block. The add unit 1350 adds the predicted block and the residual value that is output from the inverse-transform unit 1330, thereby outputting a restored image.

Accordingly, in the exemplary embodiments of the present invention, a visually noticeable image portion alone is compressed and encoded by using a masking effect of the HVS, thereby improving an image compression rate without visible deterioration of image quality.

Meanwhile, the aforementioned image encoding method of the exemplary embodiments of the present invention can be embodied as computer programs. Codes and code segments for accomplishing the exemplary embodiments of the present invention can be easily construed by programmers skilled in the art. In addition, the computer programs can be stored in a computer readable media, and be read and executed by a specific arithmetic unit, to realize the present invention. Examples of the computer readable media include magnetic tapes, optical data storage devices, and carrier waves.

While the present invention has been particularly shown and described with reference to exemplary embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention as defined by the appended claims. The exemplary embodiments should be considered in descriptive sense only and not for purposes of limitation. Therefore, the scope of the invention is defined not by the detailed description of the invention but by the appended claims, and all differences within the scope will be construed as being included in the present invention.

What is claimed is:

1. An image encoding method comprising:

creating a predicted block corresponding to a current block to be encoded using a prediction unit;

creating a residual block by estimating a difference between the current block and the predicted block using a subtraction unit;

creating a transformed residual block and a transformed predicted block by transforming the residual block and the predicted block, respectively using a transform unit; using a minimum threshold block creating unit for obtaining a minimum threshold transform coefficient which allows a corresponding pixel included in the transformed predicted block to be visually noticeable, and creating a minimum threshold block comprising the minimum threshold transform coefficient; and

using a quantization unit for determining an optimum quantization step which allows a maximum quantization error to be equal to or less than the minimum threshold transform coefficient with respect to a corresponding coefficient of the transformed residual block, and quantizing the corresponding coefficient of the transformed residual block based on the determined optimum quantization step.

2. The method of claim 1, wherein the minimum threshold transform coefficient is a just noticeable distortion estimated from the transformed predicted block.

3. The method of claim 1, wherein, when a quantization step of an i -th coefficient of the transformed residual block is Q_{step}^i , a maximum quantization error based on the quantization step is $\text{MaxE}(Q_{step}^i)$, and a minimum threshold transform coefficient corresponding to the i th coefficient of the transformed residual block is J_i , then an optimum quantization step of the i -th coefficient of the transformed residual block is determined to be a quantization step which has a maximum value among values of the quantization step Q_{step}^i satisfying $\text{MaxE}(Q_{step}^i) \leq J_i$.

4. The method of claim 1, wherein the optimum quantization step is used for a quantization step of the corresponding coefficient of the transformed residual block if a value of the optimum quantization step is greater than a value of a predetermined quantization step for the corresponding coefficient of the transformed residual block.

5. The method of claim 1, further comprising changing an average value of the optimum quantization step while main-

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taining a relative rate of the determined optimum quantization step for the corresponding coefficient of the transformed residual block.

6. An image encoding method comprising:
 creating a predicted block corresponding to a current block 5
 to be encoded using a prediction unit;
 creating a residual block by estimating a difference
 between the current block and the predicted block using
 a subtraction unit;
 creating a transformed residual block and a transformed 10
 predicted block by transforming the residual block and
 the predicted block, respectively using a transform unit;
 using a minimum threshold block creating unit for obtain-
 ing a minimum threshold transform coefficient which
 allows a corresponding pixel of the transformed pre- 15
 dicted block to be visually noticeable, and creating a
 minimum threshold block comprising the minimum
 threshold transform coefficient; and
 using a selection unit for selecting a coefficient of the
 transformed residual block to be encoded from coeffi- 20
 cients of the transformed residual block by comparing
 the minimum threshold transform coefficient with a cor-
 responding coefficient of the transformed residual
 block.

7. The method of claim 6, further comprising quantizing 25
 and entropy coding a difference between the selected coeffi-
 cient of the transformed residual block and the minimum
 threshold transform coefficient.

8. The method of claim 6, wherein the minimum threshold 30
 transform coefficient is a just noticeable distortion estimated
 from the transformed predicted block.

9. The method of claim 6, wherein an absolute value of the
 selected coefficient of the transformed residual block is
 greater than an absolute value of the minimum threshold 35
 transform coefficient.

10. An image encoding method comprising:
 creating a predicted block corresponding to a current block
 to be encoded using a prediction unit;
 creating a residual block by estimating a difference 40
 between the current block and the predicted block using
 a first subtraction unit;
 using a minimum threshold block creating unit for obtain-
 ing a minimum threshold coefficient which allows a
 corresponding pixel included in the predicted block to
 be visually noticeable, and creating a minimum thresh- 45
 old block comprising the minimum threshold coeffi-
 cient; and
 using a second subtraction unit for creating a difference
 residual block by estimating a difference between the
 minimum threshold coefficient and a corresponding 50
 coefficient of the residual block.

11. The method of claim 10, wherein the minimum thresh-
 old coefficient is a just noticeable distortion estimated from
 the predicted block.

12. The method of claim 10, further comprising setting a 55
 value of a pixel of the difference residual block to "0" if the
 value is negative.

13. An image encoding apparatus comprising:
 a prediction unit which creates a predicted block corre- 60
 sponding to a current block to be encoded;
 a subtraction unit which creates a residual block by esti-
 mating a difference between the current block and the
 predicted block;
 a first transform unit which creates a transformed residual
 block by transforming the residual block;
 a second transform unit which creates a transformed pre- 65
 dicted block by transforming the predicted block;

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a minimum threshold block creating unit which obtains a
 minimum threshold transform coefficient which allows
 a coefficient included in the transformed predicted block
 to be visually noticeable, and creates a minimum thresh-
 old block comprising the minimum threshold transform
 coefficient; and

a quantization unit which determines an optimum quanti-
 zation step which allows a maximum quantization error
 to be equal to or less than the minimum threshold trans-
 form coefficient with respect to a corresponding coeffi-
 cient of the transformed residual block, and quantizing
 the corresponding coefficient of the transformed
 residual block based on the determined optimum quanti-
 zation step.

14. The apparatus of claim 13, wherein the minimum
 threshold transform coefficient is a just noticeable distortion
 estimated from the transformed predicted block.

15. The apparatus of claim 13, wherein, when a quantiza-
 tion step of an i -th coefficient of the transformed residual
 block is Q_{step}^i , a maximum quantization error based on the
 quantization step is $\text{MaxE}(Q_{step}^i)$, and a minimum threshold
 transform coefficient corresponding to the i -th coefficient of
 the transformed residual block is J_i , then an optimum quan-
 tization step of the i -th coefficient of the transformed residual
 block is determined to be a quantization step which has a
 maximum value among values of the quantization step Q_{step}^i
 satisfying $\text{MaxE}(Q_{step}^i) \leq J_i$.

16. The apparatus of claim 13, wherein the quantization
 unit determines the optimum quantization step is used for a
 quantization step of the corresponding coefficient of the
 transformed residual block only if a value of the optimum
 quantization step is greater than a predetermined quantization
 step for the coefficients of the transformed residual block.

17. The apparatus of claim 13, wherein the quantization
 unit changes an average value of the optimum quantization
 step while a relative rate of the determined optimum quanti-
 zation step is maintained for the corresponding coefficient of
 the transformed residual block.

18. An image encoding apparatus comprising:
 a prediction unit which creates a predicted block corre-
 sponding to a current block to be encoded;
 a subtraction unit which creates a residual block by esti-
 mating a difference between the current block and the
 predicted block;
 a first transform unit which creates a transformed residual
 block by transforming the residual block;
 a second transform unit which creates a transformed pre-
 dicted block by transforming the predicted block;
 a minimum threshold block creating unit which obtains a
 minimum threshold transform coefficient which allows
 a coefficient included in the transformed predicted block
 to be visually noticeable, and creates a minimum thresh-
 old block comprising the minimum threshold transform
 coefficient; and

a selecting unit selecting a coefficient of a transformed
 residual block to be encoded from coefficients of the
 transformed residual block by comparing the minimum
 threshold transform coefficient with a corresponding
 coefficient of the transformed residual block.

19. The apparatus of claim 18, wherein the minimum
 threshold transform coefficient is a just noticeable distortion
 estimated from the transformed predicted block.

20. The apparatus of claim 18, wherein the selecting unit
 selects the coefficient of a transformed residual block to be
 encoded if an absolute value of the coefficient of the trans-
 formed residual block is greater than an absolute value of the
 minimum threshold transform coefficient.

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21. An image encoding apparatus comprising:
 a prediction unit which creates a predicted block corresponding to a current block to be encoded;
 a first subtraction unit which creates a residual block by estimating a difference between the current block and the predicted block;
 a minimum threshold block creating unit which obtains a minimum threshold coefficient which allows a corresponding pixel included in the predicted block to be visually noticeable, and creates a minimum threshold block comprising the minimum threshold coefficient;
 and
 a second subtraction unit which creates a difference residual block by estimating a difference between the minimum threshold coefficient and a corresponding coefficient of the residual block.

22. The apparatus of claim 21, wherein the minimum threshold coefficient is a just noticeable distortion estimated from the predicted block.

23. The apparatus of claim 21, further comprising a quantization unit which performs quantization by setting a value of a pixel of the difference residual block to "0" if the value is negative.

24. An image decoding method comprising:
 using an entropy decoder for reading information on an optimum quantization step, which is determined such that a maximum quantization error is equal to or less than a minimum threshold transform coefficient with respect to each coefficient of a transformed residual block, and information on a coefficient of the transformed residual block, from a received bit-stream, the coefficient being quantized according to the optimum quantization step;
 inverse-quantizing the quantized coefficient of the transformed residual block using an inverse quantization unit; and
 restoring an image by adding a predicted block for a current block to be decoded and the inverse-transformed transformed residual block using an add unit.

25. The method of claim 24, wherein the minimum threshold transform coefficient is a just noticeable distortion estimated from a transformed predicted block.

26. An image decoding apparatus comprising:
 an entropy decoder which reads information on an optimum quantization step, which is determined such that a maximum quantization error is equal to or less than a minimum threshold transform coefficient with respect to each coefficient of a transformed residual block, and information on a coefficient of the transformed residual block, from a received bit-stream, the coefficient being quantized according to the optimum quantization step;
 an inverse-quantization unit inverse-quantizing the coefficients of the transformed residual block, which are quantized according to the read optimum quantization step;
 an inverse-transform unit which outputs a residual block by inverse-transforming the quantized coefficient of the transformed residual block;
 a prediction unit which creates a predicted block for a current block to be decoded; and
 an add unit which restores an image by adding the inverse-transformed residual block and the predicted block.

27. The apparatus of claim 26, wherein the minimum threshold transform coefficient is a just noticeable distortion estimated from a transformed predicted block.

28. An image encoding method comprising:
 creating a predicted image corresponding to a current image to be encoded using a prediction unit;

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creating a residual image by estimating a difference between the current image and the predicted image using a subtraction unit;
 creating a transformed residual image and a transformed predicted image by transforming the residual image and the predicted image, respectively using a transform unit;
 using a minimum threshold block creating unit for obtaining a minimum threshold transform coefficient which allows a corresponding pixel included in the transformed predicted image to be visually noticeable, and creating a minimum threshold image comprising the minimum threshold transform coefficient; and
 using a quantization unit for determining an optimum quantization step which allows a maximum quantization error to be equal to or less than the minimum threshold transform coefficient with respect to a corresponding coefficient of the transformed residual image, and quantizing the corresponding coefficient of the transformed residual image based on the determined optimum quantization step.

29. An image encoding method comprising:
 creating a predicted image corresponding to a current image to be encoded;
 creating a residual image by estimating a difference between the current image and the predicted image;
 creating a transformed residual image and a transformed predicted image by transforming the residual image and the predicted image, respectively;
 obtaining a minimum threshold transform coefficient which allows a corresponding pixel of the transformed predicted image to be visually noticeable, and creating a minimum threshold image comprising the minimum threshold transform coefficient; and
 selecting a coefficient of the transformed residual image to be encoded from coefficients of the transformed residual image by comparing the minimum threshold transform coefficient with a corresponding coefficient of the transformed residual image.

30. An image encoding method comprising:
 creating a predicted image corresponding to a current image to be encoded using a prediction unit;
 creating a residual image by estimating a difference between the current image and the predicted image using a first subtraction unit;
 using a minimum threshold block creating unit for obtaining a minimum threshold coefficient which allows a corresponding pixel included in the predicted image to be visually noticeable, and creating a minimum threshold image comprising the minimum threshold coefficient; and
 using a second subtraction unit for creating a difference residual image by estimating a difference between the minimum threshold coefficient and a corresponding coefficient of the residual image.

31. An image encoding apparatus comprising:
 a prediction unit which creates a predicted image corresponding to a current image to be encoded;
 a subtraction unit which creates a residual image by estimating a difference between the current image and the predicted image;
 a first transform unit which creates a transformed residual image by transforming the residual image;
 a second transform unit which creates a transformed predicted image by transforming the predicted image;
 a minimum threshold image creating unit which obtains a minimum threshold transform coefficient which allows a coefficient included in the transformed predicted

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image to be visually noticeable, and creates a minimum threshold image comprising the minimum threshold transform coefficient; and

a quantization unit which determines an optimum quantization step which allows a maximum quantization error to be equal to or less than the minimum threshold transform coefficient with respect to a corresponding coefficient of the transformed residual image, and quantizing the corresponding coefficient of the transformed residual image based on the determined optimum quantization step.

32. An image encoding apparatus comprising:

a prediction unit which creates a predicted image corresponding to a current image to be encoded;

a subtraction unit which creates a residual image by estimating a difference between the current image and the predicted image;

a first transform unit which creates a transformed residual image by transforming the residual image;

a second transform unit which creates a transformed predicted image by transforming the predicted image;

a minimum threshold image creating unit which obtains a minimum threshold transform coefficient which allows a coefficient included in the transformed predicted image to be visually noticeable, and creates a minimum threshold image comprising the minimum threshold transform coefficient; and

a selecting unit selecting a coefficient of a transformed residual image to be encoded from coefficients of the transformed residual image by comparing the minimum threshold transform coefficient with a corresponding coefficient of the transformed residual image.

33. An image encoding apparatus comprising:

a prediction unit which creates a predicted image corresponding to a current image to be encoded;

a first subtraction unit which creates a residual image by estimating a difference between the current image and the predicted image;

a minimum threshold image creating unit which obtains a minimum threshold coefficient which allows a corresponding pixel included in the predicted image to be visually noticeable, and creates a minimum threshold image comprising the minimum threshold coefficient; and

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a second subtraction unit which creates a difference residual image by estimating a difference between the minimum threshold coefficient and a corresponding coefficient of the residual image.

34. An image decoding method comprising:

using an entropy decoder for reading information on an optimum quantization step, which is determined such that a maximum quantization error is equal to or less than a minimum threshold transform coefficient with respect to each coefficient of a transformed residual image, and information on a coefficient of the transformed residual image, from a received bit-stream, the coefficient being quantized according to the optimum quantization step;

inverse-quantizing the quantized coefficient of the transformed residual image using an inverse quantization unit; and

restoring an image by adding a predicted image for a current image to be decoded and the inverse-transformed transformed residual image using an add unit.

35. An image decoding apparatus comprising:

an entropy decoder which reads information on an optimum quantization step, which is determined such that a maximum quantization error is equal to or less than a minimum threshold transform coefficient with respect to each coefficient of a transformed residual image, and information on a coefficient of the transformed residual image, from a received bit-stream, the coefficient being quantized according to the optimum quantization step;

an inverse-quantization unit inverse-quantizing the coefficients of the transformed residual image, which are quantized according to the read optimum quantization step;

an inverse-transform unit which outputs a residual image by inverse-transforming the quantized coefficient of the transformed residual image;

a prediction unit which creates a predicted image for a current image to be decoded; and

an add unit which restores an image by adding the inverse-transformed residual image and the predicted image.

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